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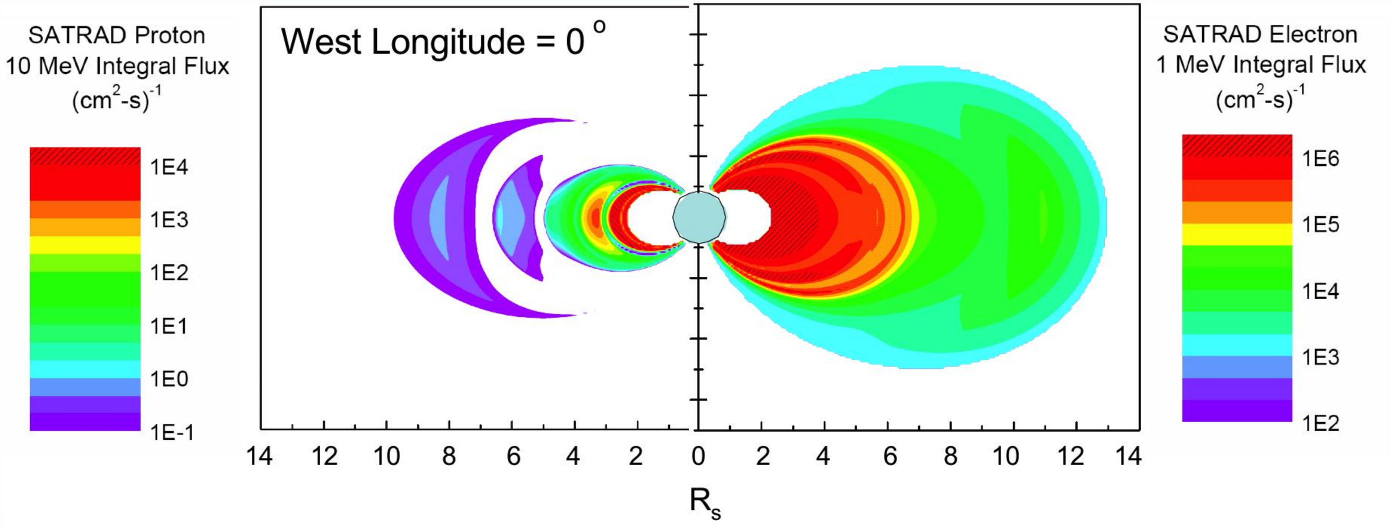
JPL ANOMALY ISSUES



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Space Weather Anomaly Concerns for JPL Robotic Mission

- **AGENDA**
  - Overview of Space Weather Anomalies on JPL Missions
  - Space Weather Products used by JPL Ops for Anomaly Mitigation and Resolution
  - Suggested Improvements in Anomaly Mitigation Procedures for JPL Missions
  - Summary

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Overview of Space Weather Anomalies on JPL Missions

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Space Weather Effects on Ops

SPACE WEATHER EFFECTS

ENVIRONMENTS

	CUMMULATIVE RAD EFFECTS	SINGLE EVENT UPSETS	LATCH-UP	SURFACE CHARGING/WAKES	INTERNAL CHARGING	POWER LOSS	VxB	SURFACE DAMAGE	GLOW	PARTICLE IMPACTS
NEUTRAL ATMOSPHERE										
E,B FIELDS				ES			e			
ULTRAVIOLET RADIATION				S				S		
INFRARED RADIATION								S		
SOLAR WIND PLASMA				s						
IONOSPHERIC PLASMA				S		e	e			
AURORA PLASMA				E						
TRAPPED RADIATION	E	Ep	E		E					
GALACTIC COSMIC RAY		P	p							
SOLAR PROTON EVENTS	Sp	Sp	Sp							
METEOROIDS						s				SEP
DEBRIS										s

Legend: **X** = Major Effect; x = Observable Effect

E,e = Europa
P,p = Pluto
S,s = Solar Probe

(Note: Assessment very dependent on spacecraft design)

Some Examples of Space Weather Effects on JPL Spacecraft Ops

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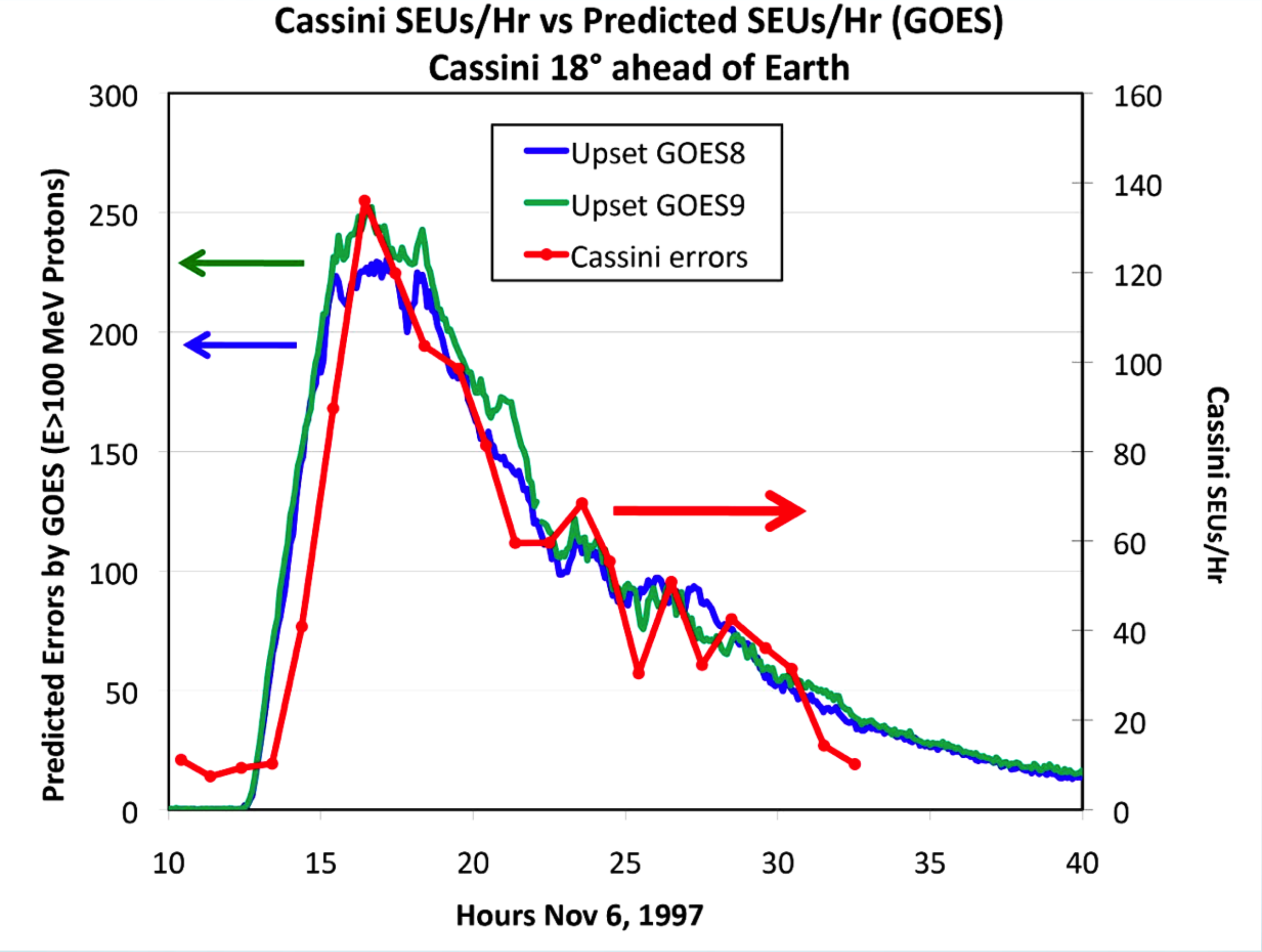
Solar Proton Event (SPE) Effects on Cassini



Lessons Learned: Real Time SPE Observations can Predict Effects on Ops (Cassini Solid State Recorder Upsets)

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Space Weather Anomalies on JPL Ops During the 2003 Halloween Storms

Oct 23: Genesis at L1 entered safe mode. Normal operations resumed on Nov. 3

Oct 24: Midori-2 Polar satellite failed (Spacecraft Charging…)

Stardust comet mission went into safe mode; recovered.

Oct 28: ACE lost plasma observations.

Mars Odyssey entered Safe mode

Oct 29: During download Mars Odyssey had a memory error

MARIE instrument powered off (has NOT recovered)

Oct 30: Both MER entered “Sun Idle” mode due to excessive star tracker events

Two UV experiments on GALEX had excess charge so high voltages turned off.

Nov. 6 Mars Odyssey spacecraft commanded out of Safe mode; operations nominal.

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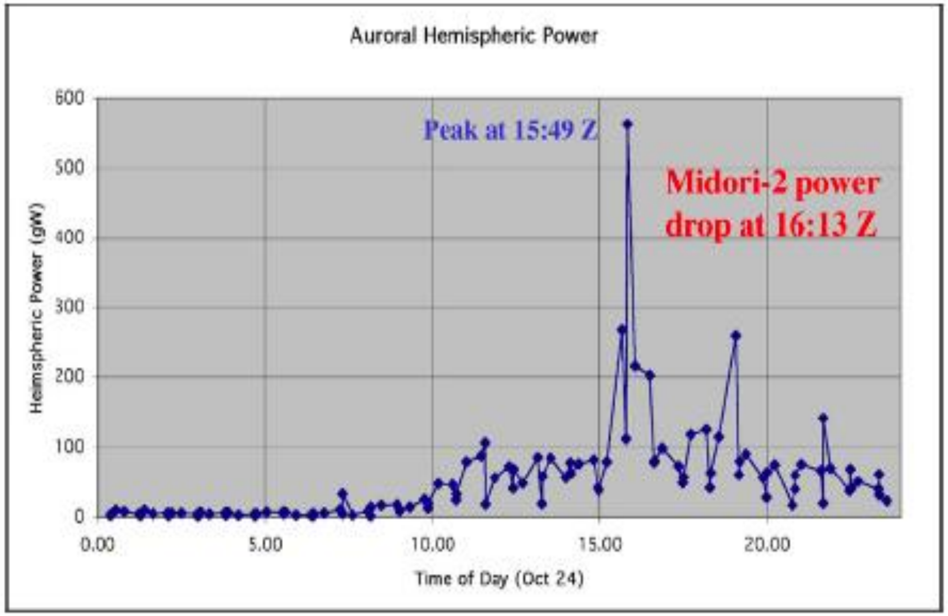
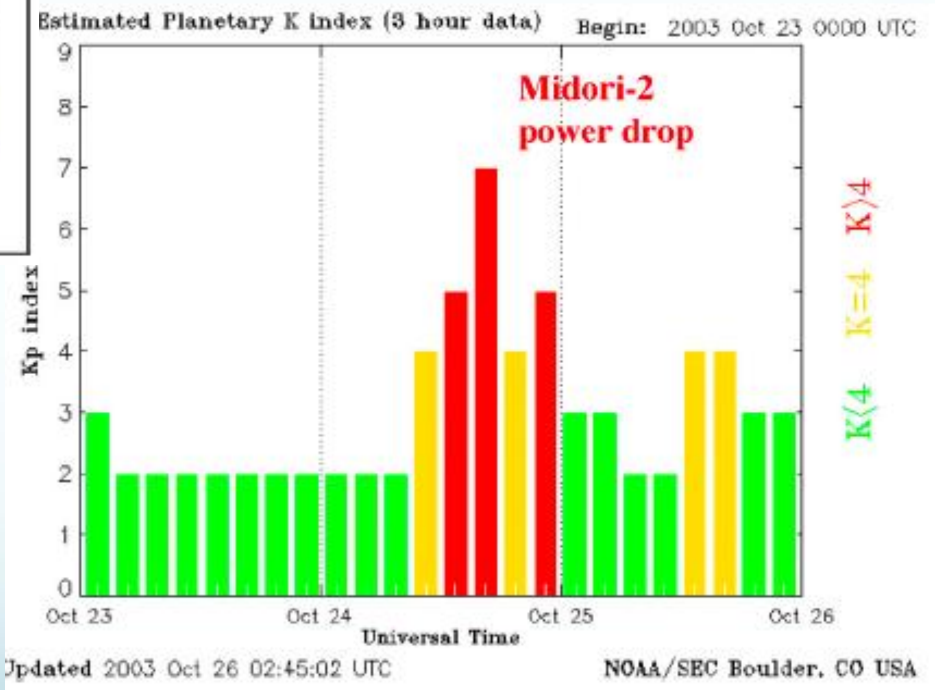
Auroral Effects on JPL Ops, Oct. 24, 2003



Lessons Learned: Geophysical Indices Critical to Rapid Anomaly Resolution for JPL Missions



Oct 24: ADEOS-Midori-2 (JPL SeaWinds Instrument) Failed. Attributed to Spacecraft Surface Charging

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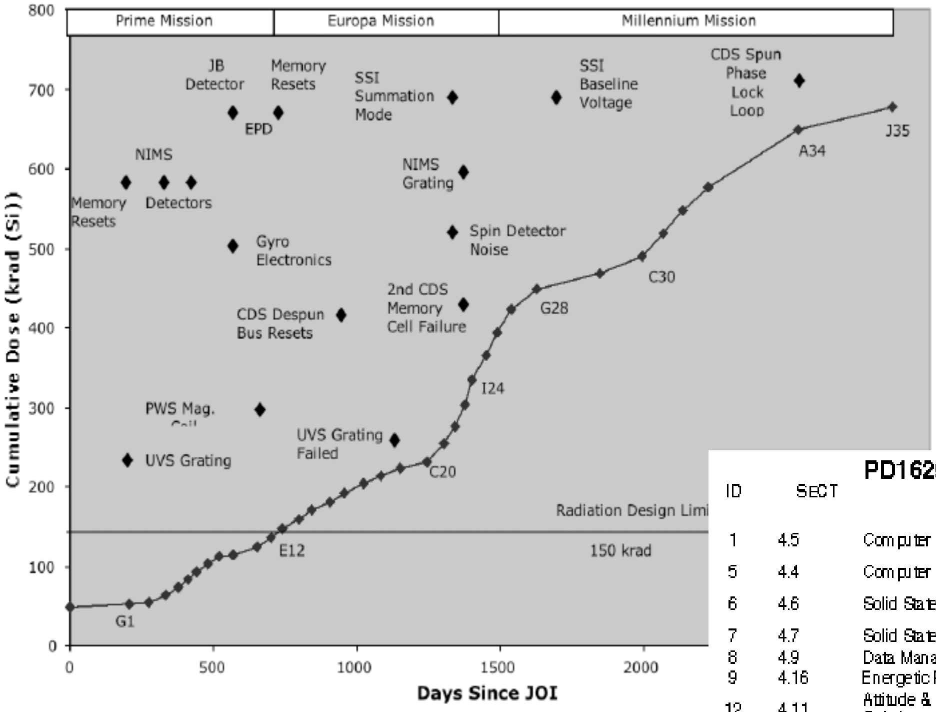
Space Weather Effects on Galileo Ops--Radiation



Lessons Learned: Forecasting can affect operations—Galileo ops modified to take account of radiation belt effects

PD1625-600 GALILEO RADIATION FAILURE SUMMARY

ID	SECT	TITLE	CATEGORY	SOURCE		FAILURE MECHANISM
1	4.5	Computer Data Subsystem Despun Interface	electronic design	radiation, noise	total dose, dose rate	common mode noise
5	4.4	Computer Data Subsystem XR-215 Phase Lock Loops	electronic part	radiation	dose rate	noise
6	4.6	Solid State Imaging Subsystem CD4xxx Timing	electronic part	radiation	total dose, dose rate	timing shifts
7	4.7	Solid State Imaging Subsystem TA10599 Opamp	electronic part	radiation	dose rate	package charging
8	4.9	Data Management Subsystem OP133 LED's	electronic part	radiation	total dose	displacement damage
9	4.16	Energetic Particle Detector "CMS" Failing Detector	electronic part	radiation	total dose	dead layer buildup
12	4.11	Attitude & Articulation Control Subsystem Gyro DG-181 Switch	electronic design, electronic part	radiation	total dose	
13	4.21	Near Infrared Mapping Spectrometer Grating Failure	electronic design, electronic part	age, radiation		
14	4.13	Attitude & Articulation Control Subsystem Star Scanner	electronic design, electronic part	age, radiation	total dose, time	photomultiplier tube ageing, browning
25	4.20	Near Infrared Mapping Spectrometer Detector Failure	electronic part, packaging design	radiation, thermal	total dose, thermal cycle	
26	4.25	Photopolarimetry Radiometry Subsystem Loss Channel	electronic part, packaging design	radiation, thermal	total dose, thermal cycle	
15	4.12	Attitude & Articulation Control Subsystem Spin Detector	electronic design, electronic part			
16	4.19	Near Infrared Mapping Spectrometer Memory Corruption	electronic design, electronic part			
17	4.23	Plasma Subsystem Detector Failure	electronic design, electronic part			
27	4.26	Plasma Wave Subsystem Search Coil	electronic part, electronic design, packaging design			

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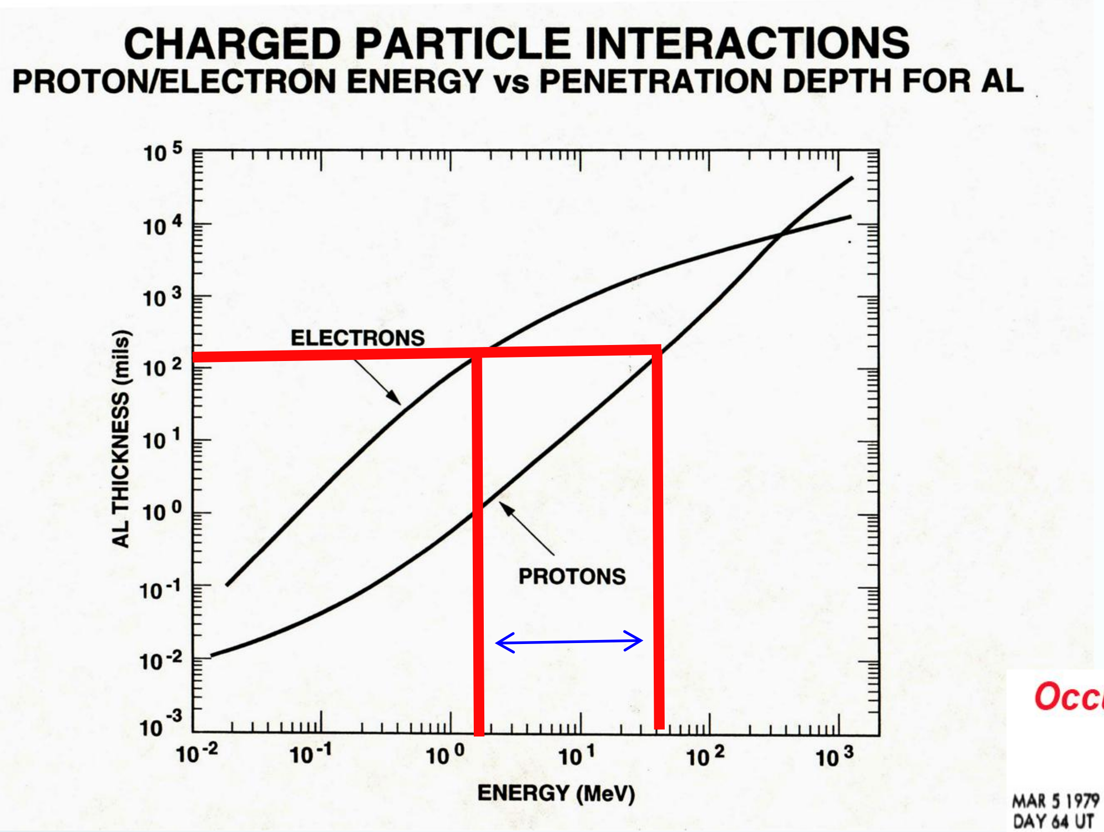
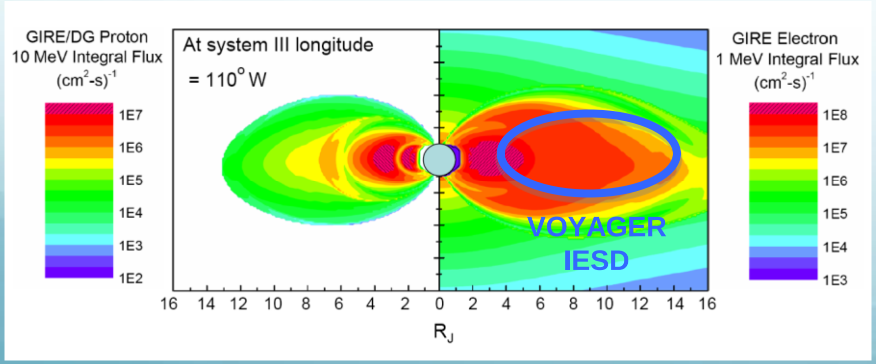
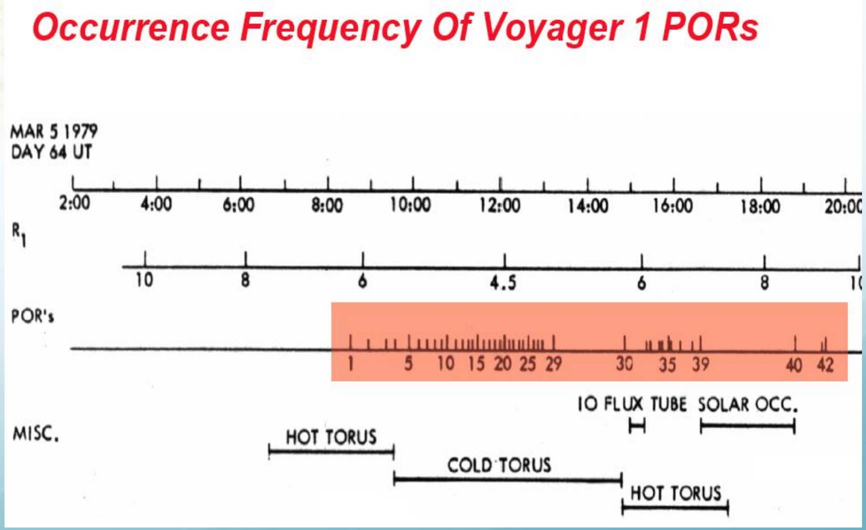
Internal Electrostatic Discharge— Attack of the Killer Electrons…



DISCHARGES IN DIELECTRICS
Lichtenberg Pattern





42 IESD Events on Voyager 1!!!

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Space Weather Products used by JPL Ops for Anomaly Mitigation and Resolution

Space Weather Products Used by JPL

- **Terrestrial**
  - GOES Products
  - Kp/Ap, AE, Dst
  - Scintillation Indices
  - Atmospheric Models (Atomic Oxygen, Drag)
  - Auroral Fluxes
  - AE8/AP8, CRRES Models
- **Solar**
  - IMF, Plasma (ACE (CIT), Soho (ESA), etc.)
  - SPE Models (JPL)
- **Planetary**
  - Trapped Radiation Models (JPL)
  - Magnetospheres
  - Jovian Radio Brightness
  - Atmospheric Models
  - Ionospheric/Plasmaspheric Models (JPL)
  - Auroral Models (JPL)
  - Comets (JPL)
  - Meteors (JPL)

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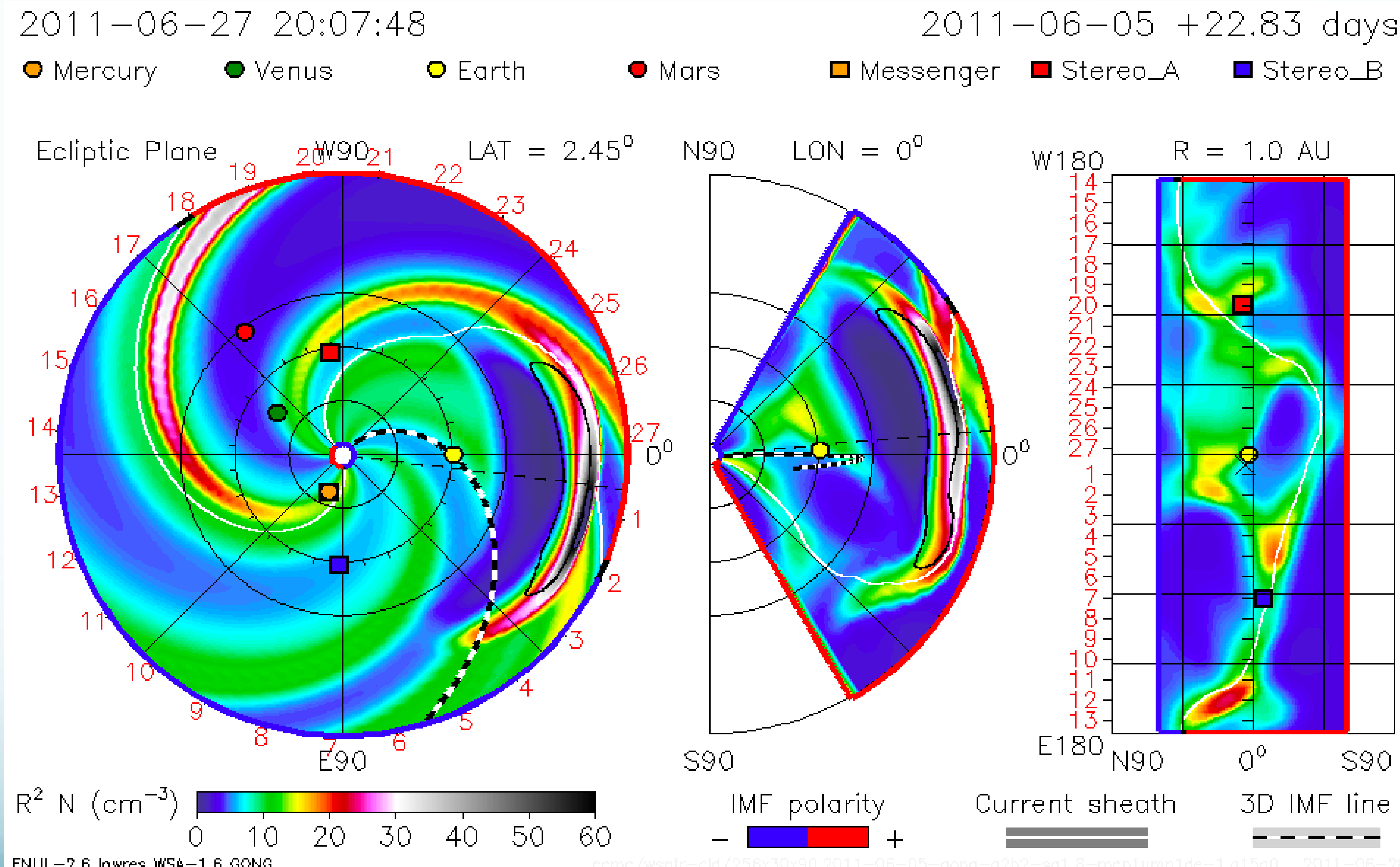
Dawn Spacecraft Anomaly—an Example



Dawn Anomaly Timeline

DESCRIPTION:

- ***21 June GSFC Space Weather Lab sent out predictions of a CME passing near Vesta on the Sun/Earth/Vesta vector on or about 27 June.***
- **Sunday, 27 June (08:32 UT), Dawn suffered an anomaly prior to its arrival at Vesta.**
- **When communications with Dawn were established during a planned DSN contact early on June 28, spacecraft was found to be in safe comm mode.**
- **The spacecraft had autonomously terminated thrusting with the ion propulsion system (IPS) approximately 21 hours earlier.**
- **Onboard fault protection detected that thrusting had been terminated, and configured the spacecraft into safe comm mode.**
- **The spacecraft was stable and healthy, with the HGA pointed at Earth and an operating telecomm system.**
- **Only identified anomaly was low pressure in IPS main and cathode Xe supply plena.**

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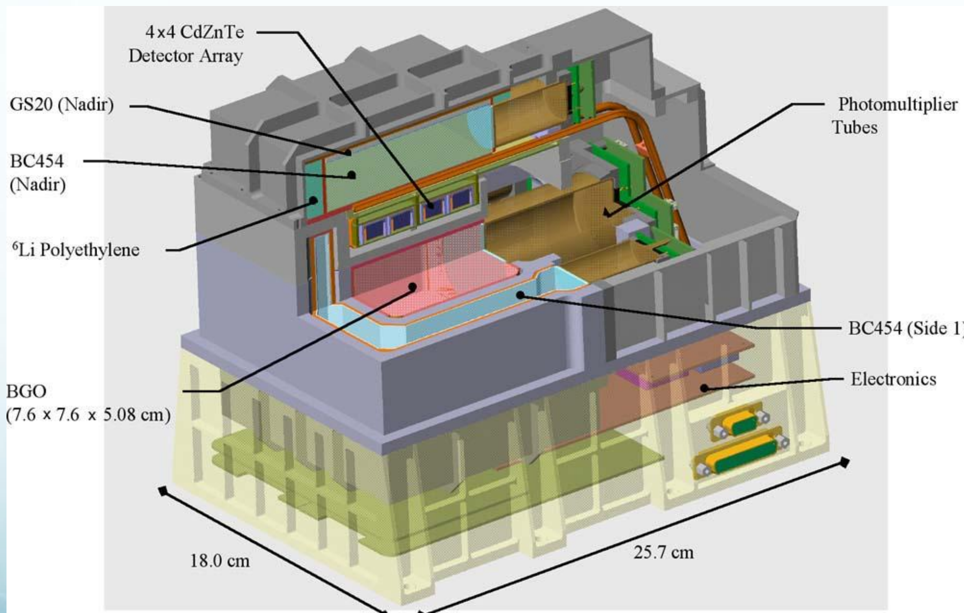
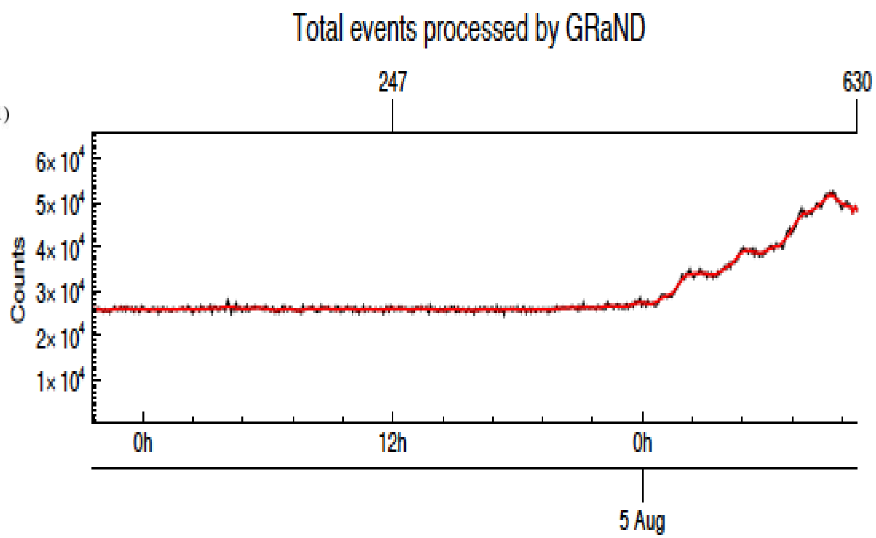
Dawn Gamma Ray and Neutron Detector (GRaND) Instrument Observations

The Dawn GRaND Instrument's background correlates with SPEs and CME high energy particles. *It did not see anything* so apparently the observation that the CME arrived at the same time as the safing event anomaly was only "a very interesting coincidence….".



Dawn GRaND Instrument

Example: Here GRaND shows gradually increasing energetic particle activity beginning 5-Aug in association with a CME. Such an increase was not seen on 27 June.



Conclusions

- Observed anomalies were fully explained by loss of power to the DCIU1/XVD circuits; No other likely (*i.e.,* single-fault) cause was identified
- Cause was narrowed to a fault in the Over Voltage Protection circuit
- Swapped to DCIU2 and resumed thrusting
- GSFC space weather warnings allowed prediction/recognition of potential space weather anomalies at Dawn
- GSFC SWL prompt response helped eliminate a potential “cause” and permitted narrowing the anomaly resolution study.

Need Space Weather Radiation Criteria for Launch Commit Poll in Countdown to Launch

JPL doesn't launch if the weather's bad…but why have Launch Commit criteria for space weather?

- Critical operations in the first few hours following launch make a spacecraft particularly vulnerable to radiation-induced Single Event Upsets (SEUs) in the spacecraft memory.
- Corrupted memory can delay time-critical operation, such as solar array deployment
- Spacecraft fault protection is typically not at full functionality until the spacecraft is in nominal operating mode.

Suggested Improvements in Anomaly Mitigation Procedures for JPL Missions

JPL Needs

PLASMAS AND SPACECRAFT CHARGING

- FOR SPACECRAFT SURFACE CHARGING, NEED TO MONITOR AND PREDICT THE TIME-VARYING PLASMA ENVIRONMENTS (REAL TIME FORECAST)

PLASMAS/RADIATION BELTS:

- NEED BETTER RADIATION BELT MODELS (BOTH AT EARTH AND THE OUTER PLANETS) FOR MISSION DESIGN (CLIMATOLOGY) AND SHORT TERM “STORM” PREDICTIONS (FORECAST)—CURRENTLY BEGINNING EVALUATION OF AE9/AP9 FOR JPL MISSIONS
- NEED TO INCORPORATE RADIATION FORECASTS INTO JPL MISSION LAUNCH CRITERIA

INTERACTION MODELING:

- MANY SPACE WEATHER MODELS NOW EXIST BUT NEED TO BE INTEGRATED TO FORECAST SYNERGISTIC EFFECTS ON SPACE OPS LIKE THE EVIRONMENTAL WORKBENCH PROGRAM (CLIMATOLOGY AND REAL TIME FORECAST)

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Summary

Summary

- **WHY DO WE CARE?**
  - SPACE WEATHER EFFECTS HAVE HAD SERIOUS IMPACTS ON JPL MISSION OPS AND ARE POTENTIALLY EXPENSIVE PROBLEMS
  - THERE ARE STILL MANY UNKNOWN EFFECTS OF SPACE WEATHER ON SPACE OPS
  - PROPER DESIGN AND FORE-KNOWLEDGE (CLIMATOLOGY AND REAL TIME FORECAST) CAN LIMIT IMPACT OF SPACE WEATHER ON OPS
- **WHAT CAN WE DO?**
  - DESIGN: EVALUATE THE MISSION AND OPS PLANS USING AN INTEGRATED APPROACH THAT INCLUDES THE SPACE WEATHER EFFECTS
  - BUILD: REQUIRE ADEQUATE TESTING (RECOMMEND ENGINEERING TEST MODEL!) IN THE RELEVANT SPACE WEATHER CONDITIONS UNDER REALISTIC OPS
  - LAUNCH: DEFINE SPACE WEATHER LAUNCH CONDITIONS FOR JPL MISSIONS
  - FLIGHT: DURING FLIGHT, EVALUATE EFFECTIVENESS OF FORECASTS AND MITIGATION METHODOLOGIES ON OPS
  - POST FLIGHT: USE OPS EXPERIENCE TO UPDATE MODELS AND DESIGN TECHNIQUES

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